

# The Rare Radiative Annihilation Decays $\bar{B}_{s,d}^0 \rightarrow J/\psi \gamma$

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## Abstract

We investigate the physics potential of the annihilation decays  $\bar{B}_{s,d}^0 \rightarrow J/\psi \gamma$  in the Standard Model and beyond. In naive factorization approach, the branching ratios are estimated to be  $\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi \gamma) = 1.40 \times 10^{-6}$  and  $\mathcal{B}(\bar{B}_d^0 \rightarrow J/\psi \gamma) = 5.29 \times 10^{-8}$ . In the framework of QCD factorization, we compute the non-factorizable corrections and get  $\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi \gamma) = 2.11 \times 10^{-7}$ ,  $\mathcal{B}(\bar{B}_d^0 \rightarrow J/\psi \gamma) = 7.65 \times 10^{-9}$ . Future measurements of these decays would be useful for testing the factorization frameworks. The smallness of these decays in the SM make them sensitive probes of New Physics. As an example, we will consider the possible admixture of (V+A) charge current to the standard (V-A) current. This admixture will give significant contributions to the decays.

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# 1 Introduction

Decays of B mesons to final states containing charmonium constitute a very sensitive laboratory for the study of electro-weak interactions, as well as the dynamics of strong interactions. The semi-inclusive  $J/\psi$  productions in B decays had ever risen tough challenges for understanding its large rate[1, 2] which require large contribution beyond color singlet model for charmonium production at  $m_b$  scale[3, 4, 5, 6, 7]. Currently its large production rate could be understood in the framework of Non-Relativistic QCD(NRQCD) effective field theory[8]. However, the momentum spectrum of  $J/\psi$ , especially the excess of slow  $J/\psi$  meson, is still hard for theoretical explanation, which may reveal interesting phenomena of the possible intrinsic charm component of the B[9], the decay  $B \rightarrow J/\psi$  baryon anti-baryon[10] and the production of  $s\bar{d}g$  hybrid[11]. The exclusive decays  $B \rightarrow J/\psi K^{(*)}$  have also attracted very extensive theoretical and experimental studies, which involve more complicated strong dynamics. The recent studies[12, 13] have shown that it is hard to account for its large rates and polarizations theoretically.

In this paper, we present a study of the radiative annihilation decays  $\bar{B}_{s,d}^0 \rightarrow J/\psi\gamma$ , which is much rarer than  $B \rightarrow J/\psi K^{(*)}$ , however, involve simpler hadronic dynamics. In naive factorization approach, these decays involve the form factors which are similar to those of the radiative leptonic decays[14, 15, 16, 17]. It is shown that the form factors could be described simply in terms of a convolution of the B meson distribution function with a perturbative kernel[15]. Beyond naive factorization approach, non-factorization contributions only arise from one loop vertex QCD corrections which can be calculate properly in the framework of QCD factorization[18]. We find  $\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi\gamma) = 1.40 \times 10^{-6}$  and  $\mathcal{B}(\bar{B}_d^0 \rightarrow J/\psi\gamma) = 5.29 \times 10^{-8}$  in naive factorization approach. With QCD factorization approach, these branching ratios are reduced to be  $\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi\gamma) = 2.11 \times 10^{-7}$  and  $\mathcal{B}(\bar{B}_d^0 \rightarrow J/\psi\gamma) = 7.65 \times 10^{-9}$ , because the effective coefficient  $a_2$  gets smaller than it in naive factorization. Such effects have also been found in two body B non-leptonic decays[18, 19, 20, 21] where the vertex-type one loop QCD corrections make  $|a_2|$  much smaller than it naive one, i.e.,  $a_2 = C_2 + C_1/N_c$ . Compared with two body non-leptonic B decays, the troublesome hard spectator scattering

contribution is absent and only the well defined vertex type nonfactorizable corrections are encountered. To this extend, the decays  $\bar{B}_{s,d}^0 \rightarrow J/\psi \gamma$  could be used to test factorization schemes. On the other hand, these decays could serve as probes for new physics activities as low energy scale. As an example, we take these decays as probes of the chirality of weak currents induced the decays  $b \rightarrow c\bar{c}s(d)$ .

The paper is organized as follows. In Sec.2, we present our study of  $\bar{B}_{s,d}^0 \rightarrow J/\psi \gamma$  in the standard model(SM). In Sec.3, we will calculate the effect of the possible admixture of  $(V + A)$  current  $g_R(\bar{q}_1 q_2)_{V+A}$  to the standard  $(V - A)$  current  $g_L(\bar{q}_1 q_2)_{V-A}$  in the decays  $\bar{B}_{s,d}^0 \rightarrow J/\psi \gamma$ . This admixture could lead to enhancement of the decays branching ratios. The effects of the small value of  $g_R/g_L$  could show up signals of the activity of New Physics.

## 2 $\bar{B}_{s,d}^0 \rightarrow J/\psi \gamma$ in the SM

We start our study from the effective Hamiltonian relevant to  $\bar{B}_q^0 \rightarrow J/\psi \gamma$  decays in the SM [22]

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} \left\{ V_{cb} V_{cq}^* [C_1(\mu) \mathcal{O}_1^c(\mu) + C_2(\mu) \mathcal{O}_2^c(\mu)] - V_{tb} V_{tq}^* \sum_{i=3}^{10} C_i(\mu) \mathcal{O}_i(\mu) \right\}. \quad (1)$$

Where  $q=s,d$  and  $C_i$  ( $i=1, \dots, 10$ ) are the effective Wilson coefficients at next-to-leading order evaluated at the renormalization scale  $\mu$ . The effective operators can be expressed explicitly as follows[22]

$$\begin{aligned} \mathcal{O}_1^c &= (\bar{c}_\alpha b_\beta)_{V-A} \otimes (\bar{q}_\beta c_\alpha)_{V-A}, & \mathcal{O}_2^c &= (\bar{c}_\alpha b_\alpha)_{V-A} \otimes (\bar{q}_\beta c_\beta)_{V-A}, \\ \mathcal{O}_3 &= (\bar{q}_\alpha b_\alpha)_{V-A} \otimes (\bar{c}_\beta c_\beta)_{V-A}, & \mathcal{O}_4 &= (\bar{q}_\alpha b_\beta)_{V-A} \otimes (\bar{c}_\beta c_\alpha)_{V-A}, \\ \mathcal{O}_5 &= (\bar{q}_\alpha b_\alpha)_{V-A} \otimes (\bar{c}_\beta c_\beta)_{V+A}, & \mathcal{O}_6 &= (\bar{q}_\alpha b_\beta)_{V-A} \otimes (\bar{c}_\beta c_\alpha)_{V+A}, \\ \mathcal{O}_7 &= \frac{3}{2} (\bar{q}_\alpha b_\alpha)_{V-A} \otimes e_c (\bar{c}_\beta c_\beta)_{V+A}, & \mathcal{O}_8 &= \frac{3}{2} (\bar{q}_\alpha b_\beta)_{V-A} \otimes e_c (\bar{c}_\beta c_\alpha)_{V+A}, \\ \mathcal{O}_9 &= \frac{3}{2} (\bar{q}_\alpha b_\alpha)_{V-A} \otimes e_c (\bar{c}_\beta c_\beta)_{V-A}, & \mathcal{O}_{10} &= \frac{3}{2} (\bar{q}_\alpha b_\beta)_{V-A} \otimes e_c (\bar{c}_\beta c_\alpha)_{V-A}. \end{aligned} \quad (2)$$

Where  $\alpha$  and  $\beta$  are the SU(3) color indices.

Under naive factorization, the  $\bar{B}_q^0 \rightarrow J/\psi \gamma$  decays are represented by Fig.1. The dominant mechanism is the radiation of the photon from the light quark in the B meson. Gen-

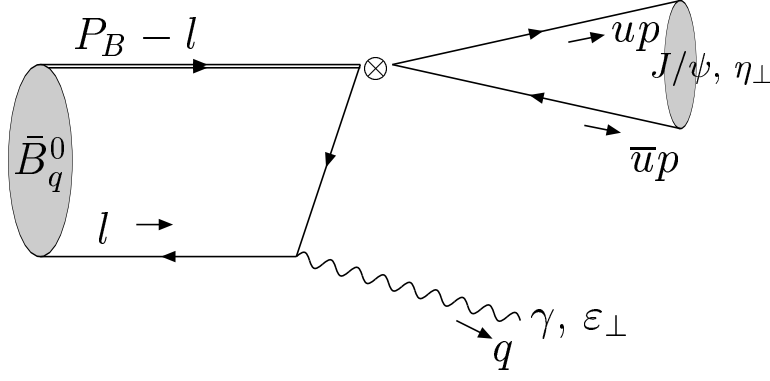


Figure 1: The Feynman diagram for the leading contribution to  $\bar{B}_q^0 \rightarrow J/\psi \gamma$  decays. The photon radiated from other quarks are suppressed by power of  $\mathcal{O}(\Lambda_{QCD}/m_b)$ .

erally the amplitude is suppressed by one order of  $\Lambda_{QCD}/m_b$  because  $J/\psi$  meson must be transversely polarized and B meson is heavy. Radiation of the photon from the remaining three quark lines is further suppressed additionally by power of  $(\Lambda_{QCD}/m_b)$ , which will be neglected in this paper.

In the heavy quark limit, the decay amplitude of  $\bar{B}_q^0 \rightarrow J/\psi \gamma$  to leading order is

$$A(\bar{B}_q^0 \rightarrow J/\psi \gamma) = \frac{G_F}{\sqrt{2}} V_{cb} V_{cq}^* \bar{a}_q \sqrt{4\pi\alpha_e} f_{J/\psi} M_{J/\psi} F_V \times \left\{ -\epsilon_{\mu\nu\rho\sigma} \eta_\perp^\mu \varepsilon_\perp^\nu v^\rho q^\sigma + i \left[ (\varepsilon_\perp \cdot \eta_\perp) (v \cdot q) - (\eta_\perp \cdot q) (\varepsilon_\perp \cdot v) \right] \right\}, \quad (3)$$

where the approximation  $V_{tb} V_{tq}^* \approx -V_{cb} V_{cq}^*$  has been made, the parameter  $\bar{a}_q$  is defined by

$$\bar{a}_q = a_2 + a_3 + a_5 + a_7 + a_9, \quad (4)$$

with  $a_{2i} = C_{2i} + \frac{1}{N_c} C_{2i-1}$  and  $a_{2i-1} = C_{2i-1} + \frac{1}{N_c} C_{2i}$ .  $\varepsilon_\perp$  and  $\eta_\perp$  are transverse polarization vectors of photon and  $J/\psi$  meson respectively. The form factor  $F_V$  is defined by [14, 15, 16, 17]

$$\langle \gamma(\varepsilon_\perp, q) | (\bar{q}b)_{V-A} | \bar{B}_q^0 \rangle = \sqrt{4\pi\alpha_e} \left[ -F_V \epsilon_{\mu\nu\rho\sigma} \varepsilon_\perp^\nu v^\rho q^\sigma + i F_A (\varepsilon_\perp \cdot v \cdot q - q_\mu \varepsilon_\perp \cdot v) \right]. \quad (5)$$

At leading order of  $\mathcal{O}(1/m_b)$ , the two form factors are given by

$$F_A = F_V = \frac{Q_q f_B M_B}{2\sqrt{2} E_\gamma \lambda_B}, \quad (6)$$

and  $\lambda_B$  is the first inverse moment of the B-meson's distribution amplitude

$$\frac{1}{\lambda_B} = \int_0^\infty dl_+ \frac{\phi_1^B(l_+)}{l_+}. \quad (7)$$

Now we can write down the helicity amplitude

$$\begin{aligned} \mathcal{M}_{++} &= -\frac{G_F}{\sqrt{2}} V_{cb} V_{cq}^* \bar{a}_q \sqrt{4\pi\alpha_e} F_V f_{J/\psi} M_{J/\psi} (2iE_\gamma), \\ \mathcal{M}_{--} &= 0. \end{aligned} \quad (8)$$

From the helicity amplitude in Eq.8, the branching ratio reads

$$\mathcal{B}(\bar{B}_q^0 \rightarrow J/\psi\gamma) = \frac{\tau_{B_q} |P_c|}{8\pi M_B^2} (|\mathcal{M}_{--}|^2 + |\mathcal{M}_{++}|^2), \quad (9)$$

here  $P_c$  is the c.m. momentum and  $\tau_{B_q}$  is the lifetime of  $\bar{B}_q^0$  meson.

For numerical analysis, we use the following input parameters[23]:

$$\begin{aligned} M_{B_s} &= 5.370 \text{ Gev}, & \tau_{B_s} &= 1.461 \text{ ps}, & m_b &= 4.8 \text{ Gev}, & V_{cb} &= 0.0412, \\ M_{B_d} &= 5.279 \text{ Gev}, & \tau_{B_d} &= 1.542 \text{ ps}, & m_c &= 1.47 \text{ Gev}, & V_{cd} &= 0.224, \\ M_{J/\psi} &= 3.097 \text{ Gev}, & \lambda_B &= 0.35 \text{ Gev} [15, 18], & N_c &= 3, & V_{cs} &= 0.996, \end{aligned}$$

the decay constants:  $f_{B_s} = 210 \text{ Mev}$ ,  $f_{B_d} = 180 \text{ Mev}$ ,  $f_{J/\psi} = 405 \text{ Mev}$ , and the Wilson coefficients at  $\mu = m_b$  scale:  $C_1 = 1.082$ ,  $C_2 = -0.185$ ,  $C_3 = 0.014$ ,  $C_4 = -0.035$ ,  $C_5 = 0.009$ ,  $C_6 = -0.041$ ,  $C_7 = -\frac{0.002}{137}$ ,  $C_8 = \frac{0.054}{137}$ ,  $C_9 = -\frac{1.292}{137}$ ,  $C_{10} = -\frac{0.263}{137}$  [22].

In naive factorization, we get the branching ratios

$$\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi\gamma) = 1.40 \times 10^{-6}, \quad (10)$$

$$\mathcal{B}(\bar{B}_d^0 \rightarrow J/\psi\gamma) = 5.29 \times 10^{-8}. \quad (11)$$

In the above calculations, non-factorizable contributions are neglected. However, the non-factorizable contributions may be important. These radiative corrections at order  $\alpha_s$  can be obtained by calculating the amplitudes in Fig.2. The QCD factorization approach advocated recently in [18] allows us to compute the non-factorizable corrections in the heavy quark limit.

In our calculation, we take the momentum of the B meson  $P_B^\mu = M_B v^\mu$  and photon flying along  $n_- = (1, 0, 0, -1)$  direction, where the four-velocity  $v = (1, 0, 0, 0)$  satisfies  $v^2 = 1$ . In the heavy quark limit, the B-meson's light-cone projection operator can be written as [19, 24]

$$M_{\alpha\beta}^B = \frac{i}{4N_c} f_B M_B \left\{ (1 + \not{v}) \gamma_5 [\Phi_1^B(\rho) + \not{n}_- \Phi_2^B(\rho)] \right\}_{\alpha\beta}, \quad (12)$$

where  $\rho$  is the momentum fraction carried by the spectator quark of the B meson and the normalization conditions are

$$\int_0^1 d\rho \Phi_1^B(\rho) = 1, \quad \int_0^1 d\rho \Phi_2^B(\rho) = 0. \quad (13)$$

For  $J/\psi$  meson, we take

$$M_{\perp\rho\sigma}^{J/\psi} = -\frac{f_{J/\psi}}{4N_c} [\not{\eta}_\perp (P_{J/\psi} + M_{J/\psi})]_{\rho\sigma} \Phi^{J/\psi}(u). \quad (14)$$

Because the charm quark is heavy, the wave function  $\Phi^{J/\psi}(u)$  is symmetric function under  $u \rightarrow 1 - u$  and should be sharply peaked around  $u = 1/2$  [11].

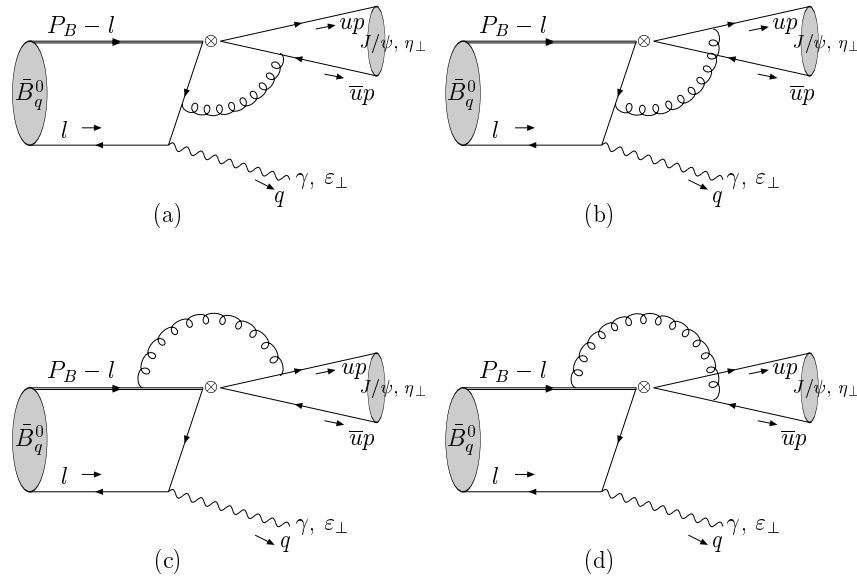


Figure 2: Non-factorizable contribution at order  $\alpha_s$ . "⊗" denote the insertions of color-octet operators  $\mathcal{O}_1^c, \mathcal{O}_4, \mathcal{O}_6, \mathcal{O}_8, \mathcal{O}_{10}$  in  $\bar{B}_q^0 \rightarrow J/\psi \gamma$ . Other diagrams with the photon radiating from remain three quark lines is suppressed and neglected.

The calculation of the non-factorizable contributions depicted in Fig.2. is straightforward. Including the contributions, the amplitudes for  $\bar{B}_q^0 \rightarrow J/\psi \gamma$  will be

$$A(\bar{B}_q^0 \rightarrow J/\psi \gamma) = \frac{G_F}{\sqrt{2}} V_{cb} V_{cq}^* \bar{a}'_q \sqrt{4\pi\alpha_e} f_{J/\psi} M_{J/\psi} F_V \times \left\{ -\epsilon_{\mu\nu\rho\sigma} \eta_\perp^\mu \varepsilon_\perp^\nu v^\rho q^\sigma + i [(\varepsilon_\perp \cdot \eta_\perp)(v \cdot q) - (\eta_\perp \cdot q)(\varepsilon_\perp \cdot v)] \right\}, \quad (15)$$

and

$$\bar{a}'_q = a'_2 + a'_3 + a'_5 + a'_7 + a'_9. \quad (16)$$

The  $\mathcal{O}(\alpha_s)$  corrections are summarized in  $a'_i$  which are calculated to be

$$\begin{aligned} a'_2 &= C_2 + \frac{C_1}{N_c} + \frac{\alpha_s}{4\pi} \frac{C_F}{N_c} C_1 F, \\ a'_3 &= C_3 + \frac{C_4}{N_c} + \frac{\alpha_s}{4\pi} \frac{C_F}{N_c} C_4 F, \\ a'_5 &= C_5 + \frac{C_6}{N_c} - \frac{\alpha_s}{4\pi} \frac{C_F}{N_c} C_6 F, \\ a'_7 &= C_7 + \frac{C_8}{N_c} - \frac{\alpha_s}{4\pi} \frac{C_F}{N_c} C_8 F, \\ a'_9 &= C_9 + \frac{C_{10}}{N_c} + \frac{\alpha_s}{4\pi} \frac{C_F}{N_c} C_{10} F. \end{aligned} \quad (17)$$

where  $C_F = (N_c^2 - 1)/(2N_c)$ , the  $\alpha_s$  terms are the non-factorizable contributions which comes from one gluon exchange between the two currents of color-octet operators  $\mathcal{O}_1^c, \mathcal{O}_4, \mathcal{O}_6, \mathcal{O}_8, \mathcal{O}_{10}$ , as shown by Fig.2. We get

$$\begin{aligned} F &= -16 - 12 \ln \frac{\mu}{M_B} - i\pi - \int_0^1 du \Phi^{J/\psi}(u) \left\{ - \left( 1 + \frac{uz}{1 - (1-u)z} \right) \ln(1-z) \right. \\ &\quad + \frac{4u-5}{1-u} \ln(u) + \left( \frac{3}{1-uz} + \frac{1}{1 - (1-u)z} \right) uz \ln(uz) + \frac{i\pi uz}{1 - (1-u)z} \\ &\quad + 2tz \left[ \frac{\ln(u)}{z(1-u)} + \frac{\ln(1-z) - i\pi}{1 - (1-u)z} + \left( \frac{1}{1-uz} - \frac{1}{1 - (1-u)z} \right) \ln(uz) \right] \\ &\quad \left. + 2 \left( \frac{t}{u} - 1 \right) \left[ Li_2 \left( \frac{u-1}{u} \right) - Li_2 \left( \frac{1-uz}{uz} \right) + Li_2 \left( \frac{1 - (1-u)z}{uz} \right) + \gamma_E \right] \right\}. \quad (18) \end{aligned}$$

Where  $z = \frac{M_{J/\psi}^2}{M_B^2}$  and  $t = \frac{m_c}{M_{J/\psi}}$ . We have neglected the difference between  $m_b$  and  $M_B$  which is a sub-leading effect in the heavy quark limit.

In the calculation, the  $\overline{MS}$  renormalization scheme is used. We neglect the small effect of box diagrams and also neglected  $l_+^2$  terms entered in the loop calculation which are the higher twist effect. Therefore, the integral involved  $\Phi_2^B(\rho)$  absents and remain integrals could be related to the form factor  $F_V$ .

To order of  $\alpha_s$  corrections, the helicity amplitudes are

$$\mathcal{M}_{++} = -\frac{G_F}{\sqrt{2}} V_{cb} V_{cq}^* \bar{a}'_q \sqrt{4\pi\alpha_e} F_V f_{J/\psi} M_{J/\psi}(2iE_\gamma), \quad (19)$$

$$\mathcal{M}_{--} = 0. \quad (20)$$

For  $\Phi^{J/\psi}(u) = 6u(1-u)$ , we obtain

$$\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi\gamma) = 2.11 \times 10^{-7}, \quad (21)$$

$$\mathcal{B}(\bar{B}_d^0 \rightarrow J/\psi\gamma) = 7.65 \times 10^{-9}. \quad (22)$$

Because the shape of the  $J/\psi$  wave function is unknown, it is worth considering other possibilities besides the asymptotic form. The delta-function form  $\Phi^{J/\psi}(u) = \delta(u - \frac{1}{2})$  as used in [25], appeals to the naive expectation of the wave function in the non-relativistic limit. Using this wave function, the results are

$$\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi\gamma) = 9.09 \times 10^{-8}, \quad (23)$$

$$\mathcal{B}(\bar{B}_d^0 \rightarrow J/\psi\gamma) = 3.22 \times 10^{-9}. \quad (24)$$

The  $\bar{B}_s^0 \rightarrow J/\psi\gamma$  decays may be measured at Tevatron and LHC in the future. The decays  $\bar{B}_d^0 \rightarrow J/\psi\gamma$  could be studied in the planning super B factories at KEK and SLAC succeeded to Belle and BaBar. Potentially they could be enhanced by New Physics and the enhancement might be measured at those facilities.

### 3 An admixture of $(V + A)$ current in the $\bar{B}_{s,d}^0 \rightarrow J/\psi\gamma$

B decays are known to be governed by weak couplings and small mixing matrix elements. These decays are therefore very sensitive to new kinds of interactions and in particular to right-handed couplings [26]. It is conventionally assumed that the B-decays proceed via the



pure  $(V - A)$  current in the SM. However, it turns out to be surprisingly difficult to exclude the possibility that the dominant B decays occur via a  $(V + A)$  coupling[27]. The  $(V+A)$  coupling has been studied in Ref. [28, 29, 30]. In the annihilation B-decays  $\bar{B}_{s,d}^0 \rightarrow J/\psi \gamma$ , there is the possible admixture of  $(V + A)$  charged current  $g_R(\bar{q}_1 q_2)_{V+A}$  to the standard  $(V - A)$  current  $g_L(\bar{q}_1 q_2)_{V-A}$ . The small value of  $g_R/g_L$  is not ruled out so far and can be sought for as one possible sign of New Physics. In what following, we will examine the effect of possible admixture.

Assuming the admixture of  $(V + A)$  charge currents  $(b \rightarrow c)$  and  $(c \rightarrow q)$  to the SM  $(V - A)$  currents, the effective four-fermion interaction operators for  $\bar{B}_q^0 \rightarrow J/\psi \gamma$  here can be written as

$$\begin{aligned}\mathcal{O}_1^c &= [(\bar{c}_\alpha b_\beta)_{V-A} + \xi(\bar{c}_\alpha b_\beta)_{V+A}] \otimes [(\bar{q}_\beta c_\alpha)_{V-A} + \xi'(\bar{q}_\beta c_\alpha)_{V+A}], \\ \mathcal{O}_2^c &= [(\bar{c}_\alpha b_\alpha)_{V-A} + \xi(\bar{c}_\alpha b_\alpha)_{V+A}] \otimes [(\bar{q}_\beta c_\beta)_{V-A} + \xi'(\bar{q}_\beta c_\beta)_{V+A}],\end{aligned}\quad (25)$$

with  $\xi = g_R/g_L$  for current  $(b \rightarrow c)$ ,  $\xi' = g'_R/g'_L$  for current  $(c \rightarrow q)$ . Here we use the approximation  $\bar{a}_q = a_2$  and  $\bar{a}'_q = a'_2$ .

The amplitude for  $\bar{B}_q^0 \rightarrow J/\psi \gamma$  is

$$\begin{aligned}A(\bar{B}_q^0 \rightarrow J/\psi \gamma) &= \frac{G_F}{\sqrt{2}} V_{cb} V_{cq}^* \sqrt{4\pi\alpha_e} f_{J/\psi} M_{J/\psi} F_V \\ &\times \left\{ (1 + \xi') a_2 \left[ - (1 + \xi) \epsilon_{\mu\nu\rho\sigma} \eta_\perp^\mu \varepsilon_\perp^\nu v^\rho q^\sigma + i(1 - \xi)(\varepsilon_\perp \cdot \eta_\perp)(v \cdot q) \right] \right. \\ &+ \left. (1 - \xi') \frac{\alpha_s}{4\pi} \frac{C_F}{N_C} C_1 F \left[ (\xi - 1) \epsilon_{\mu\nu\rho\sigma} \eta_\perp^\mu \varepsilon_\perp^\nu v^\rho q^\sigma + i(1 + \xi)(\varepsilon_\perp \cdot \eta_\perp)(v \cdot q) \right] \right\}.\end{aligned}\quad (26)$$

The branching ratios can be read

$$\begin{aligned}\mathcal{B}(\bar{B}_q^0 \rightarrow J/\psi \gamma) &= \frac{\tau_{B_q} |P_c|}{8\pi M_B^2} \frac{G_F^2}{2} |V_{cb} V_{cq}^*|^2 4\pi\alpha_e f_{J/\psi}^2 M_{J/\psi}^2 F_V^2 4E_\gamma^2 \\ &\times \left\{ \left| (1 + \xi') a_2 + (1 - \xi') \frac{\alpha_s}{4\pi} \frac{C_F}{N_C} C_1 F \right|^2 + \xi^2 \left| (1 + \xi') a_2 - (1 - \xi') \frac{\alpha_s}{4\pi} \frac{C_F}{N_C} C_1 F \right|^2 \right\}.\end{aligned}\quad (27)$$

Where the factor  $\xi^2$  stems from  $\xi(\bar{c}b)_{V+A}$ . Because  $\xi$  is a small constant, in what follows we will neglect  $\xi^2$ .

Using the  $\Phi^{J/\psi}(u) = 6u(1 - u)$ , branching ratios are

$$\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi \gamma) = (0.46 + 1.27\xi' + 10.61\xi'^2) \times 5.23 \times 10^{-7}, \quad (28)$$

$$\mathcal{B}(\bar{B}_d^0 \rightarrow J/\psi \gamma) = (0.44 + 1.19\xi' + 10.71\xi'^2) \times 1.98 \times 10^{-8}. \quad (29)$$

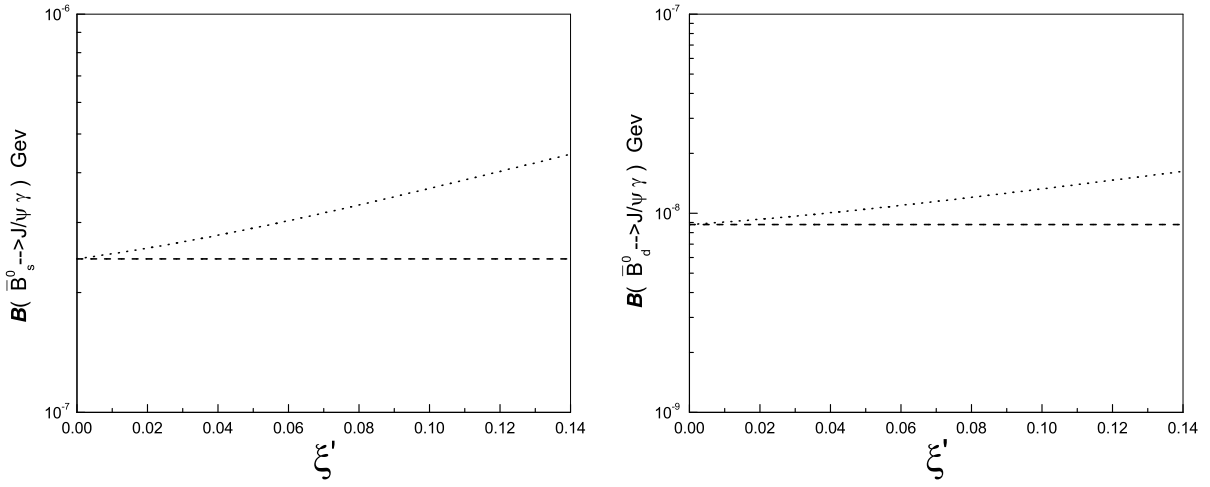


Figure 3:  $\mathcal{B}(\bar{B}_{s,d}^0 \rightarrow J/\psi \gamma)$  as a function of  $\xi' = g'_R/g'_L$ . The dash lines are the SM predictions and the dot lines are the results of including a small admixture of (V+A) quark current.

We can see that the branching ratios of these decays are very sensitive to the possible presence of the admixture of right hand current. Comparing with the SM predictions, these decays are enhanced. The numerical results are displayed as an illustration in Fig.3.

## 4 Conclusion

We have studied the radiative annihilation decays  $\bar{B}_{s,d}^0 \rightarrow J/\psi \gamma$  within the framework of QCD factorization approach. Physically, the factorization method is applicable because the transverse size of  $J/\psi$  is small in the heavy quark limit. We have shown that the non-factorizable radiative corrections at order  $\alpha_s$  change the magnitude significantly compared to the leading-order result corresponding to the naive factorization. In naive factorization, we find  $\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi \gamma) = 1.40 \times 10^{-6}$  and  $\mathcal{B}(\bar{B}_d^0 \rightarrow J/\psi \gamma) = 5.29 \times 10^{-8}$  which are much larger than  $\mathcal{B}(\bar{B}_s^0 \rightarrow J/\psi \gamma) = 2.11 \times 10^{-7}$  and  $\mathcal{B}(\bar{B}_d^0 \rightarrow J/\psi \gamma) = 7.65 \times 10^{-9}$  in the framework of QCD factorization at order of  $\alpha_s$ . It is interesting to note that these decays involve simpler hadronic dynamics than two-body B non-leptonic decays. Experimental measurements would be very useful for understanding the mechanics of  $J/\psi$  productions and testing the factorization frameworks. Simultaneously these decays also are the background

for the interesting decays  $\bar{B}_{s,d}^0 \rightarrow \mu^+ \mu^- \gamma$ . On the other hand, these decays may be sensitive to New Physics. As an illustration, we have investigated the effects of the admixture of right-hand currents. We find that these decays are sensitive to admixture of the right-handed ( $c \rightarrow s, d$ ) current and the effect of the admixture of right-handed ( $b \rightarrow c$ ) current is negligible small. Experimentally these decays could be studied at CERN LHC and the planning super high luminosity B factories at KEK and SLAC.

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